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Supplement of

Tropospheric eddy feedback to different stratospheric conditions in idealised baroclinic life cycles

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Supplementary material

Figures S1a and b show the evolution of energetics for the different cut-off experiments described in Section 4, Figures S1c and d show the corresponding anomalies from experiment T. The experiments shown in Figure S1 do not use surface friction (the cases with surface friction will be shown later in Fig. S3). In both diagnostics, ΔMKE and EKE, both sets of experiments (with either weak or strong lower-stratospheric winds in the initial conditions) show characteristics similar to the other experiments in the respective set, while the two sets differ in various way from each other in terms of their energetic evolution.

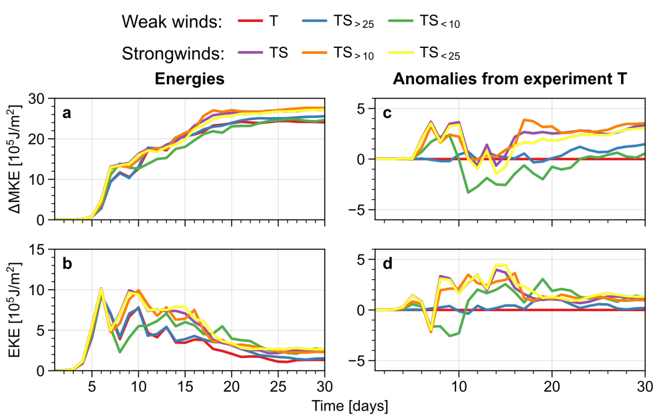

Figure S1. Evolution of mean kinetic energy change (top) and eddy kinetic energy (bottom) for different experiments. The left column shows the full energies, the right column shows the anomalies from experiments T. The experiments displayed here do not include surface friction. Energies are displayed as vertically integrated and horizontally averaged energy densities.

A prominent difference between the two sets is the increase in ΔMKE in the final state of experiments with relatively strong winds in the lower stratosphere, compared to experiments with weak winds. This difference in ΔMKE is, as also explained for Figure 3 in Subsection 3.2, associated with the meridional shift of the tropospheric jet.

Note that the energetics of experiment $TS_{<10}$ seems to share characteristics with experiments of both sets, although its final state ΔMKE is most similar to the other experiments with weak lower-stratospheric winds. Recall that in terms of final state zonal mean zonal wind (Figure 10) experiment $TS_{<10}$ showed consistent signs of a jet shift signature, although a relatively weak one. As also discussed in Section 4 this could potentially be explained by the finite transition depth of the transition function $\eta(z)$ in Equation A3, or the partial projection of the stratospheric jet onto various tropospheric characteristics, like vertical shear or tropopause height.

The analysis of MKE is less trivial in systems with surface friction (e.g., the experiments performed in Section 3) since friction leads to a constant energy dissipation near the surface and thus a constant drop in MKE throughout the lice cycle. Hence the system does not reach a steady 'final state'. To analyse the energetics of a system with surface friction (and simplify the comparison to experiments without friction) it can therefore be useful to look at the change in MKE associated with conservative processes. It is well known that the decay phase of the baroclinic life cycle is associated with a general flow of energy from EKE to MKE, mostly driven by the barotropic conversion of energy and thus the convergence of eddy momentum fluxes. The tendency of mean state energy via the barotropic conversion of eddy energy is given as

$$\left(\partial_t \bar{E}\right)_{barotr.} = \left\langle \frac{\bar{u}\partial_\phi \left(\overline{u'v'}\cos^2\phi\right)}{ga\cos^2\phi} \right\rangle, \tag{S1}$$

where $\bar{E}$ is the total energy of the zonal mean state, u and v are zonal and meridional wind, respectively, ϕ is latitude, g is the gravitational acceleration, a the Earth's radius, overbars denote zonal averages and primes the deviation from the zonal mean. Angle brackets describe a northern hemisphere horizontal average on a pressure surface and a corresponding vertical integration over the entire depth of the atmosphere.

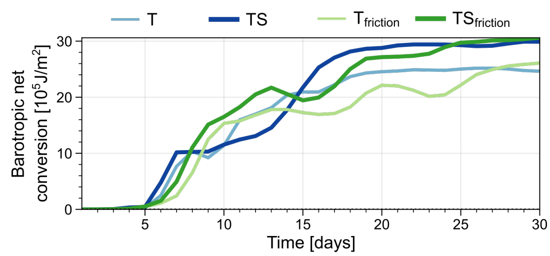

Figure S2. Net energy change due to the barotropic conversion shown in Equation S1 for experiments with and without stratospheric jet (T and TS) and with and without surface friction (subscript and no subscript).

Figure S2 shows the net conversion of eddy energy to mean state energy during the life cycle in experiments T and TS for systems with and without surface friction, respectively. We find the experiments including a stratospheric jet (TS and $TS_{friction}$) to show increased net barotropic conversion of energy compared to experiments with tropospheric jet only (T and $T_{friction}$), consistent with the associated jet shift described in Section 3.3 and the increase in MKE in a system without surface friction when a stratospheric jet is introduces (see Fig. S1). Note that Figure S2 further shows that the net energy change due to barotropic conversion during the life cycle is essentially the same in experiments with and without surface friction.

To analyse the evolution of energetics for cut-off experiments discussed in Section 4 for a system that includes surface friction, Fig. S3 shows the corresponding time series of EKE and net energy change due to barotropic conversion for experiments with either strong or weak winds in the lower stratosphere. We find experiments with relatively strong winds to correspond to generally increased barotropic conversion of energy over the course of the life cycle compared to experiment with weak winds.

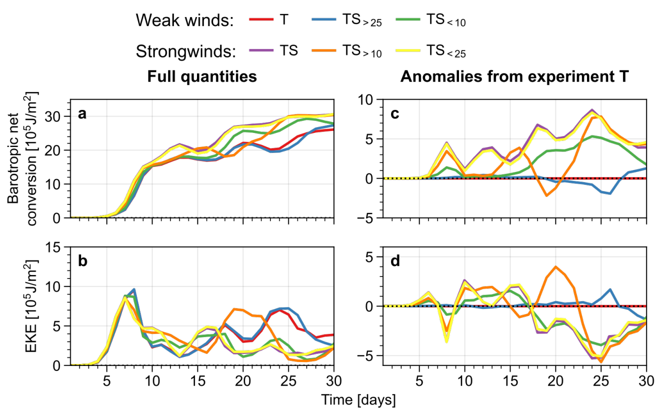

Figure S3. Net energy change due to the barotropic conversion shown in Equation S1 (top) and eddy kinetic energy (bottom) for different experiments (compare with Fig. S1). The left column shows the full energies, the right column shows the anomalies from experiments T. The experiments displayed here include surface friction and all quantities are vertically integrated and horizontally averaged. Note that the curves for the cases TS and $TS_{<25}$ are almost identical.

Since, as discussed above, the barotropic net change in energy is a measure for the change in MKE due to conservative processes the corresponding enhanced barotropic conversion for experiments with strong lower-stratospheric winds can be associated with a poleward shift and acceleration of the midlatitude jet in the final state of these cases, consistent with our analysis of the energetics for systems without surface friction (see Fig. S1) and our findings in Section 4. Further we find experiments $TS_{<10}$ and $TS_{>10}$ to (again) share characteristics with both groups, which can potentially be explained by the finite transition depth of the stratospheric jet in these experiments, as also discussed earlier for the case without surface friction.